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Scanning Electron Microscope Studies of Some Early Miocene Diatoms from the Equatorial Pacific Ocean with Descriptions of Two New Species, *Actinocyclus jouseae* Barron and *Actinocyclus nigriniae* Barron

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Scanning electron microscope (SEM) and light microscope (LM) studies are used to propose and describe two new species, *Actinocyclus jouseae* Barron, sp. nov. and *Actinocyclus nigriniae* Barron, sp. nov. from lower Miocene sediments from equatorial Pacific ODP Site 1219. Parallel SEM and LM studies reveal that *Thalassiosira bukryi Barron* should be transferred to *Azpeitia* and suggest that *Actinocyclus barronii* Radionova is likely to be a variety of *A. radionovae* Barron

During the study of the biostratigraphy of diatoms from lower Miocene (24–17 Ma) sediments of equatorial Pacific ODP Site 1219 (7°48.019′N, 142°00.940′W; 5063 m water depth) (Barron, in press), two species of *Actinocyclus* were observed that were not described by either Barron (1983) or Radionova (1991). Description of these new taxa and clarification of the taxonomic relationships of three other early Miocene diatoms from ODP 1219 warrants detailed study under LM and SEM. The purpose of this paper is to detail the valve ultrastructure of these fossil taxa and resolve their taxonomic position.

Methods and Materials

For the biostratigraphic study of Barron (in press), Cores 4H through 6H (*ca.* 24.5 to 17.0 Ma) of ODP Hole 199-1219A were sampled at 50 cm intervals, with occasional samples taken at 30 cm intervals. Approximately 1 g of material was placed in a 250 ml beaker, disaggregated with a wooden stirring rod, and covered with distilled water. Dilute (*ca.* 3%) hydrochloric acid was then added to remove the calcium carbonate. After the reaction ceased, the sample was washed with distilled water and centrifuged at 1200 rpm for 4 minutes duration in order to bring the solution to a neutral pH. After completion of the washing process, strewn slides were prepared by transferring the suspended material with a disposable pipette to a 22 × 40 mm coverslip, which was then dried on a hot plate and mounted with Naphrax on a 25 × 75 mm glass slide.

These slides were examined in their entirety under a light microscope (Leitz Ortholux) at magnification ×500, with identifications checked at ×1250. The LM photography was completed using a Spot Insight v. 4.0 digital camera on a Leica DML microscope. SEM studies were completed on selected samples with a Leo 1450VP microscope.

Descriptions of New Species

Actinocyclus jouseae Barron, sp. nov.

Plate 1, figs. 1, 4, 5; Plate 2, figs. 1, 2.

Nomenclatural synonym: *Actinocyclus challengeri* Jousé in Jousé, (ed.), 1977, pl. 57, figs. 10, 24–25, 36, nom invalid (no description). This name is a later homonym of *A. challengeri* O'Meara, 1876.

Description.— Diameter 33 to 95 µm. Linear rays of areolae increasing in size from 8–9 in 10 µm near the center to about 5 in 10 µm near the margin. Typically each primary (or sub-primary) ray is joined by one secondary ray. High (4–5 µm high) mantle near margin covered by dense areolae, about 8–10 in 10 µm. Prominent pseudonodule (circular, about 0.7 µm in diameter) located at crest of margin. Valve surface undulated, with a raised marginal region, which occupies about one third of the valves diameter. This is followed inward by an abrupt depression and a gentle rise to the valve's center. Primary radial areolar rays extend from the valve's center to the raised marginal region. These are separated by three shorter, secondary areolar rays.

Comments.— *Actinocyclus jouseae* resembles the early middle Miocene diatom, *A. ingens* var. *nodus* Baldauf in Baldauf and Barron (1980) in that the valve is undulated with a raised center and it possesses a dense radial, linear pattern of areolae. Whereas the areolae of *A. jouseae* increase in size from 8 to 9 in 10 µm near the center to about 5 in 10 µm near the margin, the areolae of *A. ingens* var. *nodus* decrease in size toward the margin (5 areolae in 10 µm near the center to 9 areolae in 10 µm near the margin). This character gives the areolar pattern of *A. jouseae* a finer, denser appearance than that of *A. ingens* var. *nodus*.

Derivation of name.— In honor of Anastasia P. Jousé, diatomist and pioneer diatom stratigrapher.

Material examined.— Holotype: CAS accession number 625066, CAS slide number 221091, ODP 1219A-4H-4. 58–59 cm (Plate 1, figure 1), Deposited at the California Academy of Sciences, San Francisco; Paratypes: CAS slide number 221090, ODP 1219A-4H-4, 8–9 cm (Plate 1, figure 4); CAS slide number 221092, ODP 1219A-4H-5, 8–9 cm (Plate 1, figure 5).

Stratigraphic range.— early Miocene (20.0–19.1 Ma) (Barron, in press).

Actinocyclus nigriniae Barron, sp. nov.

Plate 1, figs. 2, 3, 6, 7; Plate 2, figs. 3. 4.

Nomenclatural synonyms: *Cestodiscus* sp. 6 of Schrader, 1976, pl. 12, fig. 4.; *Cestodiscus kugleri* sensu Fourtanier, 1991, pl. 1, fig. 5.

Description.— Diameter 15 to 70 µm. Number of rays: three to four rudimentary rays in small specimens to 15 in larger specimens. Areolae decrease slightly in size from 8 in 10 µm near valve center to 11–12 in 10 µm near margin. Steep mantle, densely areolated 11–12 areolae in 10 µm. Prominent rounded pseudonodule located near crest of submarginal ring. Valves dimorphic, convex and concave, larger specimens tend to be flatter; smaller specimens tend to be domed. Distinctive "star-like" hyaline rays, which consist of a primary areolar row beginning near the center of the valve, and three to four additional rays of areolae on either side of the primary row, beginning at regular distances toward the margin. Note: Similar to *Cestodiscus praerapax* Radionova, 1991, pl. IV, figs. 1, 12; however, it lacks stripes on margin (N. Radionova, 2005, written commun.)

Comments.— *Actinocyclus nigriniae* resembles *Cestodiscus kugleri* Lohman 1974; however, its radial hyaline rays are less step-like in appearance and its valves possess a prominent pseudonodule on their raised, submarginal ring. *Actinocyclus nigriniae* is also similar to *Cestodiscus praer-*

apax Radionova, 1991, pl. IV, figs. 1, 12; however, it lacks stripes on margin (N. Radionova, 2005, written commun.)

Derivation of name.— In honor of Cathy Nigrini, radiolarian biostratigrapher.

Material examined.— Holotype: CAS accession number 625068, CAS slide number 221093, ODP 1219A-5H-6, 110–111 cm (Plate 1, figure 6). Deposited at the California Academy of Sciences, San Francisco. Isotypes: CAS slide number 221093, ODP 1219A-5H-6, 110–111 cm (Plate 1, figure 2); CAS slide number 221093, ODP 1219A-5H-6, 110–111 cm (Plate 1, figure 3); CAS slide number 221093, ODP 1219A-5H-6, 110–111 cm (Plate 1, figure 7).

Stratigraphic range.— early Miocene (22.7–22.3 Ma) (Barron, in press).

New Combination

***Azpeitia bukryi* (Barron) Barron, n. comb.**
Plate 3, figs. 1–5; Plate 4, figs. 1–5.

Basionym: *Thalassiosira bukryi* Barron, 1983:511, plate IV, fig. 1.

Original description.— "Flat, round valve 20 to 60 µm in diameter. Hexagonal areolae (about 7 in 10 µm) arranged in a sublinear to eccentric pattern in the central ¾s of the valve with 2 to 4 marginal eccentric rows of progressively smaller areolae (9 to 12 in 10 µm). Areolae pattern resembles that of *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. A small hyaline central area about 1–2 µm in diameter is often present, especially in larger forms, commonly containing a rounded central nodule. Numerous small pores dispersed over the valve face separated by 3 to 4 of the larger areolae. Marginal apiculi separated by 7 small areoale. Thin striated margin (1 um in width) with 10 radial striae in 10 µm."

Holotype.— USNM 348710, Plate IV, fig. 1, sample DSDP 77B-28-6, 28–30 cm

Emended description.— *Azpeitia bukryi* (Barron) Barron possesses a ring of weakly stalked, rimoportulae opening on the valve/mantle interface (Plate 4, figures 1, 3) that are all similar in appearance (Plate 4, figure 3). Although no distinct annulus is present (Plate 3, figures 3–5), larger valves commonly possess a slightly off-center central process (rimoportulae) that is surrounded by a hyaline area (compare Plate 3, figures 1–3). When viewed under the SEM (Plate 3, figures 3–5), the eroded remains of this central rimoportulae shows little or no external projection (Plate 3, figure 5) in a manner similar to that of *Azpeitia tabularis* (see Figure XIV, 1B of Fryxell et al., 1986). Numerous interlocular pores appear on the valve's surface (Plate 3, figures 1–5; Plate 4, figure 4) that are assumed to be rimoportulae. The internal openings of these rimoportulae, however, are eroded in the specimens examined so far under the SEM and are not diagnostic (Plate 4, figure 5). Because satellite pores of strutted processes are normally preserved in fossil material even when the tubes of strutted processes have been eroded (Hasle, 1985), it is assumed that these processes are labiate processes.

Areola are loculate with external cribra lying slightly below the valve surface (Plate 4, figures 2, 4), arguing against placement in *Thalassiosira*. Elongated areolae separate the tube-like chambers of the marginal rimoportulae (Plate 3, figures 3–4; Plate 4, figure 3). This distinctive marginal structure gives the appearance of being striae in LM (Plate 3, figures 1–2). Girdle bands have not yet been observed in the fossil material of *A. bukryi*.

Comments.— *Azpeitia* is "characterized by valves with a nearly central labiate process often on the edge of an annulus, a ring of labiate processes on the valve mantle, specialized areolar patterns of the mantle differing from those on the face of the valve, and two or more (usually three) hyaline girdle bands including a wide valvocopula" (Fryxell et al. 1986).

The regular ring of marginal rimoportulae, the shallow mantle with a valve structure differing from that of the valve face, the loculate areolae with external cribra all support transfer of *T. bukryi* to *Azpeitia*. Similarly, like many species of *Azpeitia*, *T. bukryi* seems to have preferred warmer waters during its early Oligocene to early Miocene range (Barron et al. 2004).

The marginal rimoportulae, structure of the shallow mantle and presence of numerous, scattered rimoportulae on the valve surface closely resemble those of *Azpeitia biannulata* Sims in Mahood et al. (1993), which was described from the lower Oligocene of Prydz Bay, Antarctica.

Stratigraphic range.— early Oligocene to early Miocene (33.1–17.5 Ma) (Barron et al. 2004; Barron, in press).

Comparison of *Actinocyclus barronii* Radionova and *A. radionovae* Barron

Radionova (1985, 1987, 1991) studied early Miocene diatoms from DSDP Sites 63, 65, 66, 166, 289, 574, 575, providing SEM illustrations of many taxa and describing five new species, *Actinocyclus barronii*, *A. mutabilis*, *A. praellipiticus*, *Cestodiscus umbonatus*, and *C. praerapax*. Although her species *A. barronii* closely resembles *A. radionovae* Barron 1983, Radionova (1991) stated that it differed from *A. radionovae* by its having (1) a considerably smaller undulation of the valve, (2) the absence of shortened lines of areolae, (3) the presence of hyaline ribs surrounding the central hyaline field. During the study of the early Miocene diatoms of ODP 1219A, it became clear that further taxonomic study was necessary to distinguish the two species of *Actinocyclus*.

Actinocyclus barronii Radionova, 1985

Actinocyclus barronii Radionova, 1985:72, pl. 1, fig. 1; Radionova, 1991:65, pl. V, figs. 2, 4.

Description (taken from Radionova [1991] because an English translation for that paper was available).— "Valve round, sometimes oval, 60–100 μm, slightly concave. Central part of valve (1/3 of its diameter) occupied by a flat hyaline field. This field has a polyangle as star-shaped and connects with the rest of the valve by hyaline ridges, which continue in the line of areolae and reach to the margin of the valve. Pseudonodule large, without operculum. On the mantle of the valve occur 8–10 rimoportulae, which on the external surface are ended by a side aperture, which is a little smaller than the psuedonodule. Mantle is short (low), margin with rough striae."

Comments.— Extensive examination of Site 1219 material reveals that specimens assignable to *A. barronii* possess shortened lines of areolae (Plate 5, fig. 2) and appear to only differ from the considerable variation in the morphology of *A. radionovae* (Plate 5, figs. 1, 2–6) by the much-reduced undulation of their valves. It is not clear what Radionova (1991) means by hyaline ribs surrounding the central hyaline field (compare Plate 5, figs. 1–2, 5). Given also that the range of specimens assignable to *A. barronii* falls completely within the range of *A. radionovae*, it would appear that *A. barronii* represents a variety of *A. radionovae*. This hypothesis would have to be confirmed by an examination of Radionova's (1985) type material of *A. barronii*.

Stratigraphic range.— early Miocene (19.9–19.1 Ma) (Barron, in press).

Actinocyclus radionovae Barron, 1983

Actinocyclus radionovae Barron, 1983:504, pl. III, figs. 1–3; pl. IV, figs. 4–6; Barron, 1985, pl. 1, fig. 2; Radionova, 1991:65, pl. V, fig. 1.

Description (**Barron, 1983**).— "circular valve with undulating surface 40 to 100 μm in diameter. Hyaline central area 10 to 25 μm in diameter with primary and secondary rows beginning at different distances from the valve's center, giving a 'star burst' appearance. Submarginal area with eroded labiate processes similar to those of Cestodiscus arranged radially every 7 to 10 µm. Margin 2 µm wide with 9 to 13 striae every 10 µm. Prominent rounded luminate pseudonodule located near the margin."

COMMENTS.— In the present study considerable variation has been observed in forms assigned to *A. radionovae*. Both concave valves with hyaline centers (the type concept) and convex valves with centers filled by continuation of the areolar rays appear to occur, especially amongst smaller (<50 µm diameter) forms (Plate 5, figures 1, 3–6).

STRATIGRAPHIC RANGE.— early Miocene (22.0–19.1 Ma) (Barron, in press).

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Plates

Plate 1

1 *Actinocyclus jouseae* Barron n. sp. Holotype, CAS slide number 221091, pseudonodule at 5 o'clock, ODP 1219A-4H-4. 58–59 cm.

2, 3 *Actinocyclus nigriniae* Barron n. sp., Isotypes, CAS slide number 221093, pseudonodules at 10 o'clock and 1 o'clock, ODP 1219A-5H-6, 110–111 cm.

4a,4b *Actinocyclus jouseae* Barron n. sp., Paratype, CAS slide number 221090, low and high focus, pseudonodule just below 3 o'clock, ODP 1219A-4H-4, 8–9 cm.

5 *Actinocyclus jouseae* Barron n. sp., Paratype, CAS slide number 221092, larger form with more complex rays, pseudonodule at 9 o'clock, ODP 1219A-4H-5, 8–9 cm.

6 *Actinocyclus nigriniae* Barron n. sp., Holotype, CAS slide number 221093, pseudonodule at 1 o'clock, ODP 1219A-5H-6, 110–111 cm.

7 *Actinocyclus nigriniae* Barron n. sp., Isotype, CAS slide number 221093, pseudonodule at 2 o'clock, ODP 1219A-5H-6, 110–111 cm.

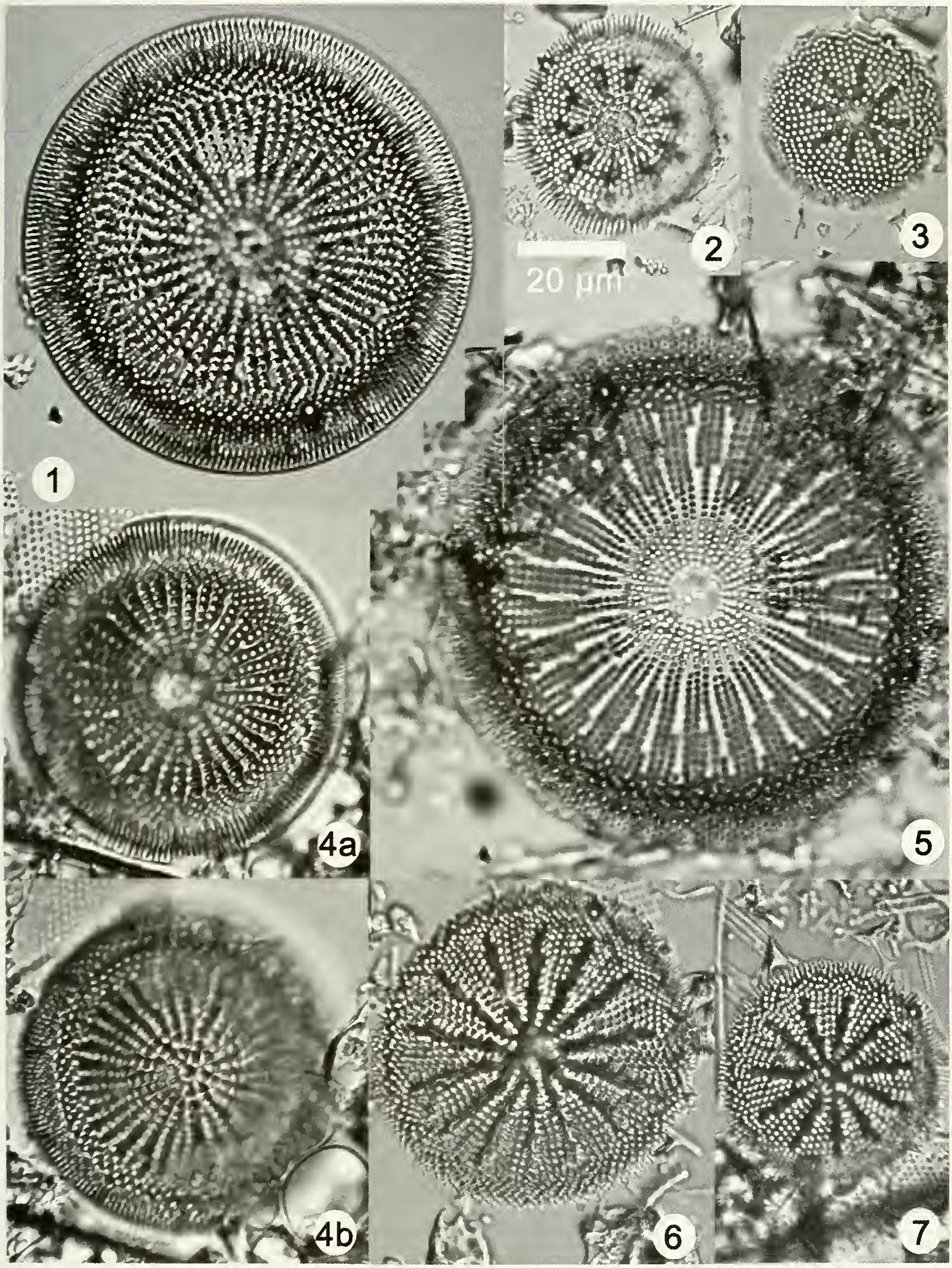

1
2
3
20 µm
4a
5
4b
6
7

Plate 2

Scale bars for Figs. 1, 2a, 3a, 4a = 20 µm; for Figs. 2b, 3b, 4b = 5 µm.

1 *Actinocyclus jouseae* Barron n. sp., external view of valve, Isotype CAS accession number 625066, ODP 1219A-4H-4, 58–59 cm.

2a *Actinocyclus jouseae* Barron n. sp., internal view of valve, Isotype CAS accession number 625066, ODP 1219A-4H-4, 58–59 cm.

2b Close-up of Fig. 2a showing pseudonodule and eroded labiate processes on steep mantle.

3a *Actinocyclus nigriniae* Barron n. sp., external view of valve with concave center, Isotype, CAS accession number 625068, ODP 1219A-5H-6, 110–111 cm.

3b Close-up of margin of Fig. 3a showing pseudonodule.

4a *Actinocyclus nigriniae* Barron n. sp., internal view of valve, Isotype, CAS accession number 625068, ODP 1219A-5H-6, 110–111 cm.

4b Close-up of internal opening of pseudonodule of Fig. 4a.

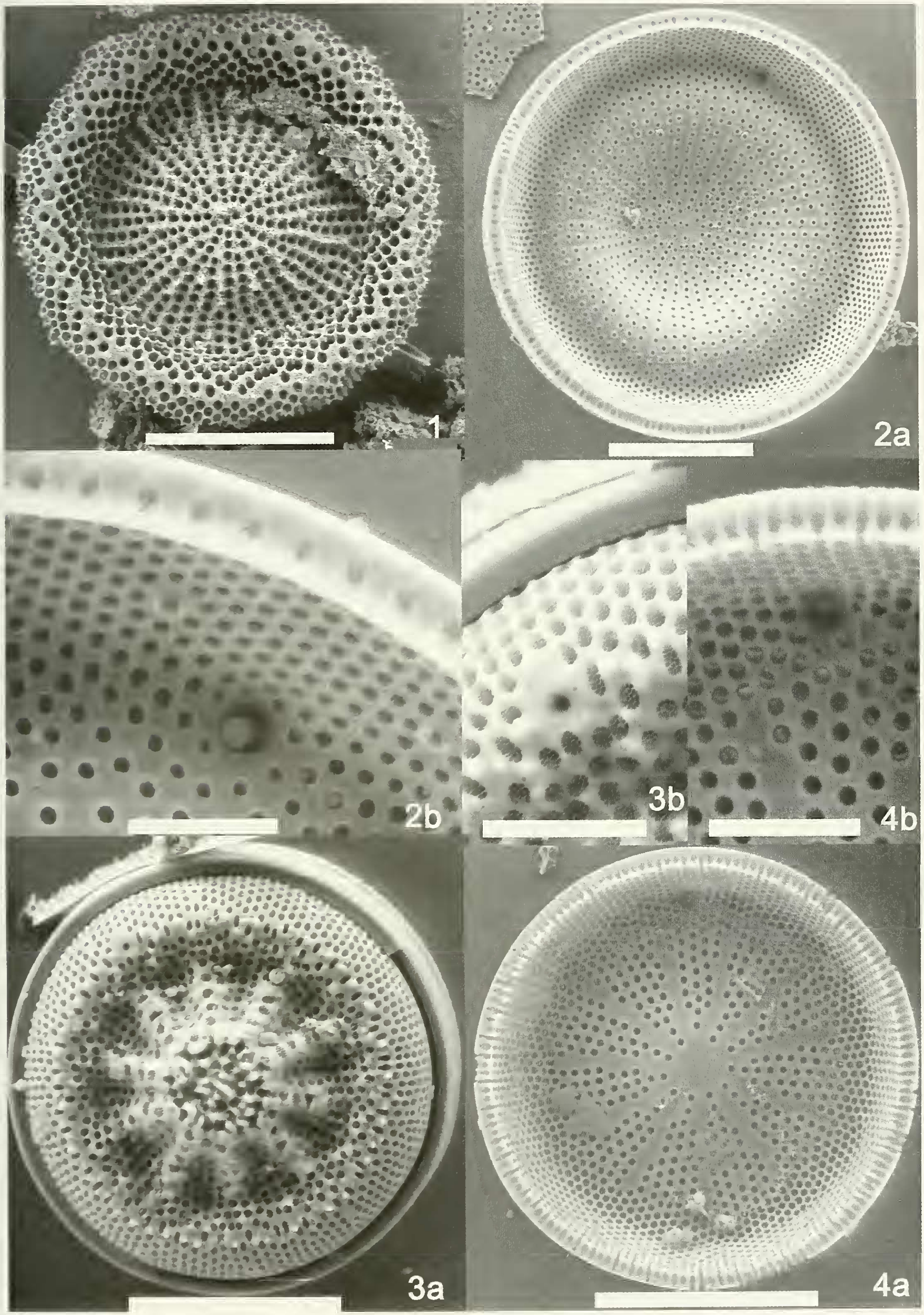

1
2a
2b
3b
4b
3a
4a

Plate 3

Azpeitia bukryi (Barron) Barron n. comb., LM and SEM photos.
1, 2 LM views of valve, ODP 1219A-6H-1, 108–109 cm, scale bar = 20 μm.
3 SEM, External view of valve ODP 1219A-5H-1, 108–109 cm.
4 SEM, External view of valve, showing possible eroded central process, ODP 1219A-4H-4, 58–59 cm.
5 Detail of fig. 4 (enlarged 3X).

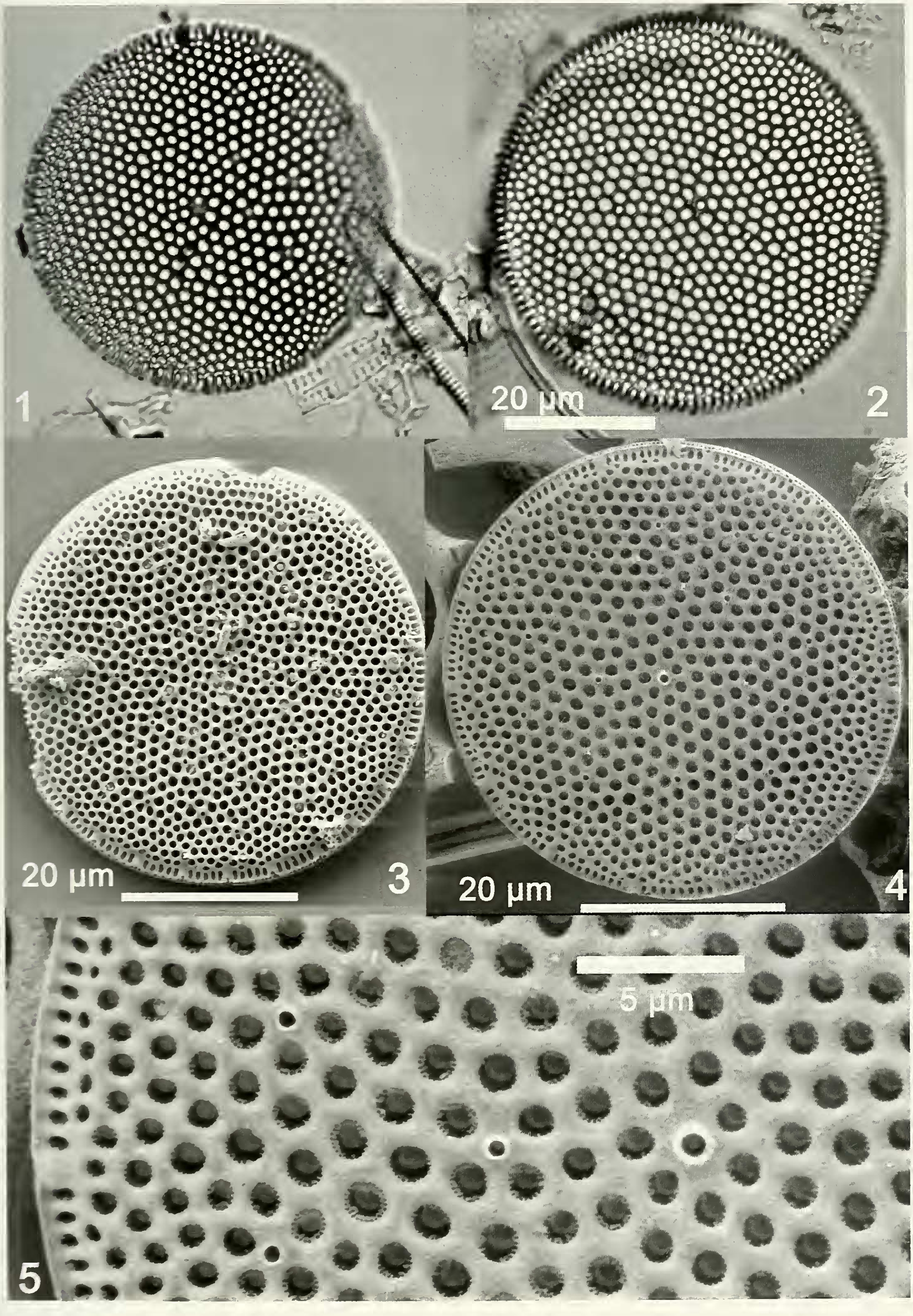

1
20 μm
2
20 μm
3
20 μm
4
5 μm
5

Plate 4

Azpeitia bukryi (Barron) Barron n. comb., SEM photos.
1 Internal view of eroded marginal labiate processes, ODP 1219A-5H-1, 108–109 cm.
2 Detail of margin, ODP 1219A-5H-1, 108–109 cm.
3 Internal view of eroded valve, ODP 1219A-4H-4, 58–59 cm.
4 Detail of cribra and small openings, ODP 1219A-5H-1, 108–109 cm.
5 Detail of Fig. 3 (enlarged 2X).

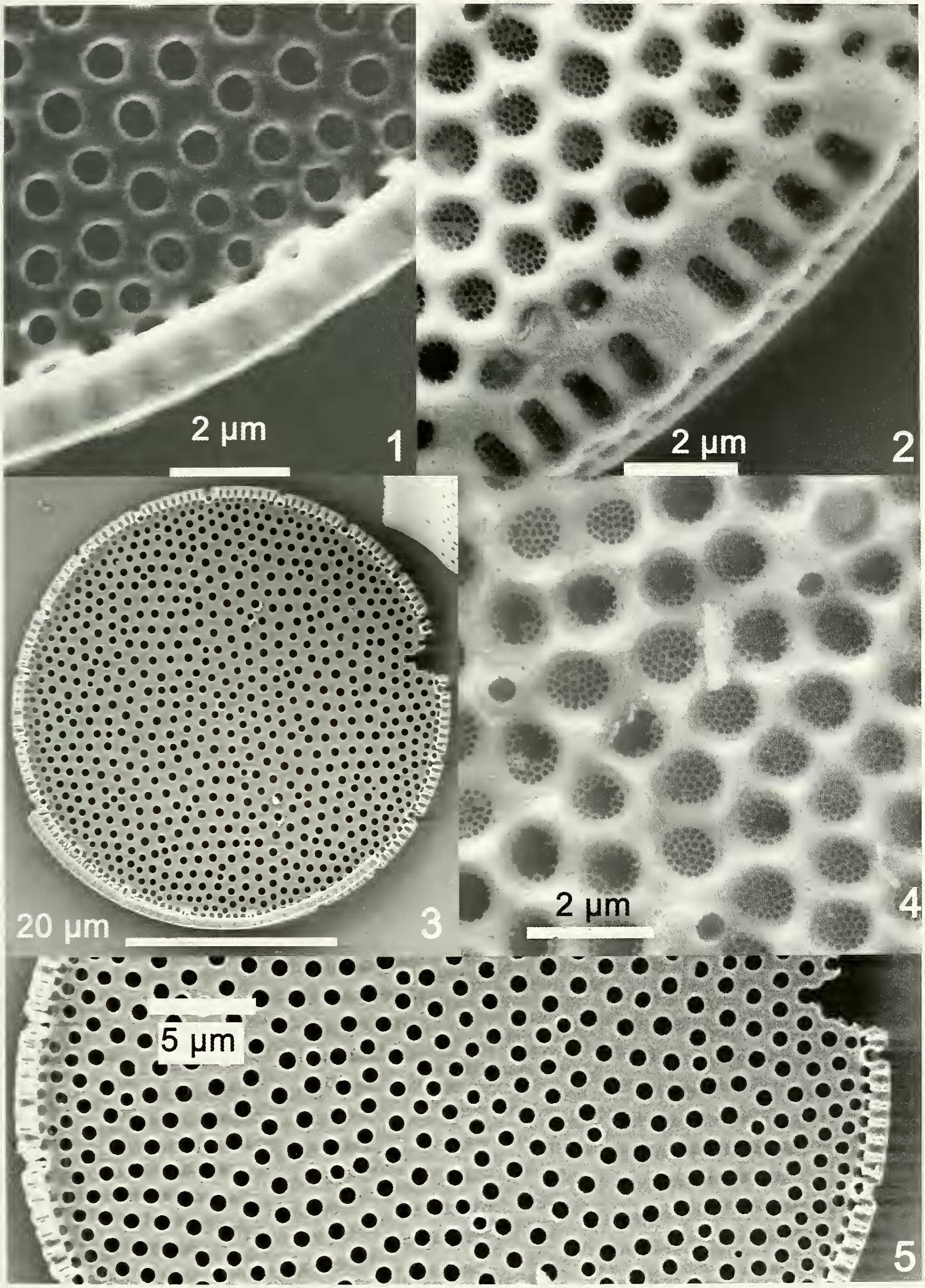

2 µm
1
2 µm
2
20 µm
3
2 µm
4
5 µm
5

Plate 5

Scale bars for all figs. = 20 µm

1 *Actinocyclus radionovae* Barron, external SEM, ODP 1219A-4H-4, 58–59 cm.

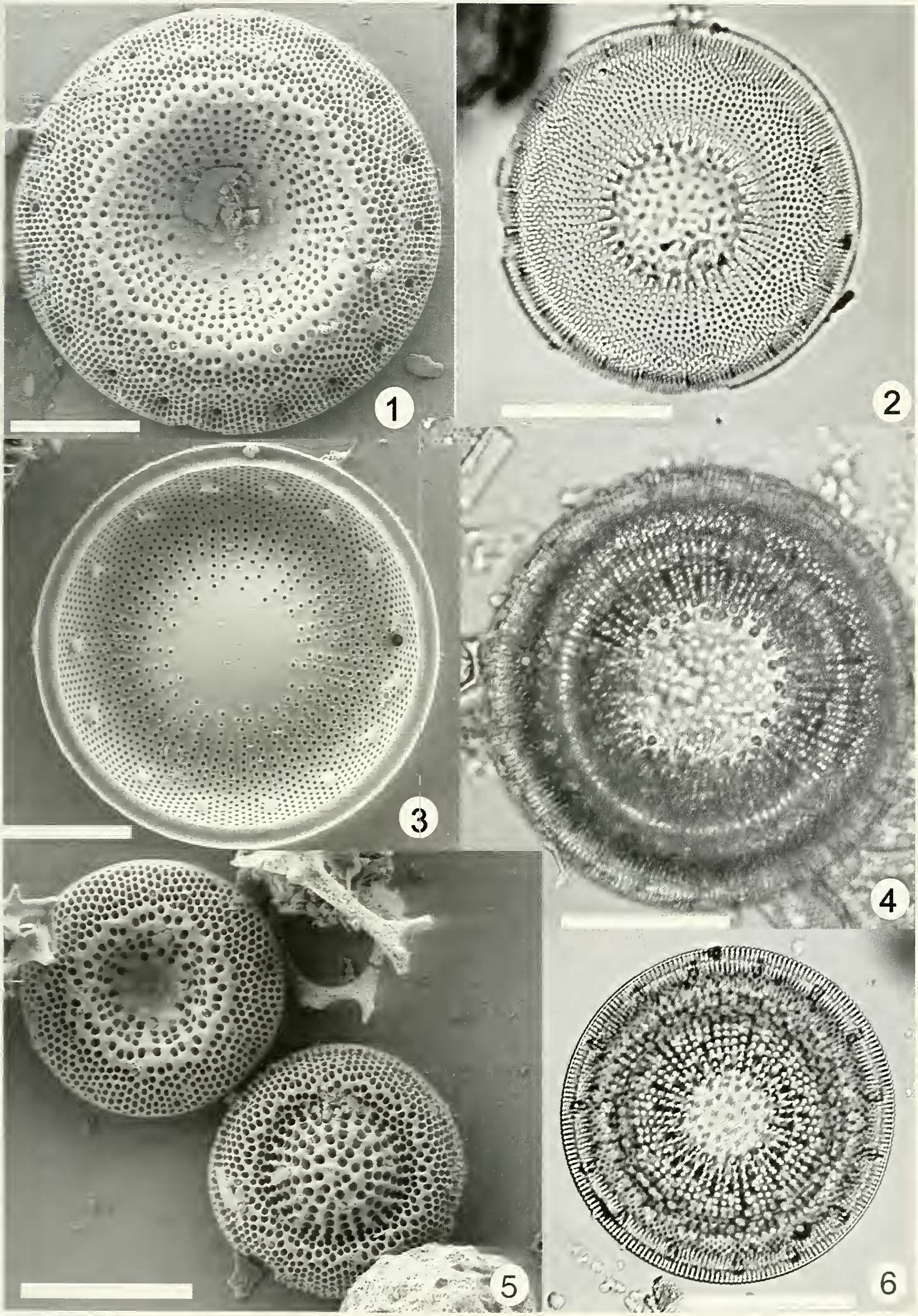
2 *Actinocyclus barronii* Radionova, external LM, pseudonodule at 1 o'clock, ODP 1219A-4H-4, 58–59 cm.

3 *Actinocyclus radionovae* Barron, internal SEM, showing mushroom-shaped labiate processes, and internal opening of pseudonodule at 3 o'clock, ODP 1219A-4H-4, 58–59 cm.

4 *Actinocyclus radionovae* Barron. Holotype of Barron, 1983, USNM 348702, DSDP 495-33-5, 72–76 cm.

5 Concave and convex specimens of *A. radionovae*. s.l. ODP 1219A-4H-4, 58–59 cm.

6 *Actinocyclus radionovae* Barron, pseudonodule at 5 o'clock, ODP 1219A-4H-4, 58–59 cm.


1
2
3
4
5
6